ROAD TRACKING AND ANOMALY DETECTION IN AERIAL IMAGERY

Technical Note 158

March 1978

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The research reported herein was supported by the Advanced Research Projects Agency of the Department of Defense, under Contract No. DAAG29-76-C-0057

To be presented at the ARPA Spring 1978 Image Understanding Workshop.

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **MAR 1978**	2. REPORT TYPE	3. DATES COVERED **00-03-1978 to 00-03-1978**

4. TITLE AND SUBTITLE **Road Tracking and Anomaly Detection in Aerial Imagery**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **SRI International,333 Ravenswood Avenue,Menlo Park,CA,94025**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

ROAD TRACKING AND ANOMALY DETECTION IN AERIAL IMAGERY

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ABSTRACT

This report describes a new procedure for tracking road segments and finding potential vehicles in imagery of approximately 1 to 3 feet per pixel ground resolution. This work is part of a larger effort by SRI International to construct an image understanding system for monitoring roads in aerial imagery.

INTRODUCTION

This report describes a new procedure for tracking road segments and finding potential vehicles in imagery of approximately 1 to 3 feet per pixel ground resolution. This research is part of a larger effort by SRI International to build a "knowledge based road expert," described by Barrow and Fischler elsewhere in these proceedings.

The overall effort is directed towards specific problems that arise in processing aerial photographs for such military applications as cartography, intelligence, weapon guidance, and targeting. A key concept is the use of a generalized digital map data base to aid in the interpretation of imagery.

OBJECTIVES

The primary objectives of the overall "road expert system" are to analyze images to:

(a) Find road fragments in low- to medium-resolution images

(b) Track roads in medium- to high-resolution images

(c) Find anomalies on roads

(d) Interpret anomalies as vehicles, shadows, signposts, surface markings, etc.

The road tracking algorithm discussed here is started with the position of the center and direction of a road fragment found by part a). The nominal road width is supplied either from the data base or by an image analysis function that can determine the width of a road fragment. The road tracker produces two forms of output: a point list describing the track of the road center and a binary image of all points in the road that are anomalous and might belong to vehicles. In the complete road-expert system, this image will then be analyzed by part d) to screen false alarms and interpret the remaining anomalies.

ALGORITHM DESCRIPTION

Figure 1a shows a representative road scene containing segments of a multilane freeway, with a few vehicles and road surface markings (painted arrows and words in the leftmost lane). The wear patterns in the lanes correspond linearly with the road. The vehicles and other anomalies stand out as being quite different from the pattern of the road.

The basic road-tracking algorithm exploits the above observations. Successive road intensity cross-sections (RCS) taken perpendicular to the direction of the road showed a high degree of correlation, which suggested that road tracking could be accomplished by using cross-correlation. The location of the correlation peak was used to maintain alignment with the road center and to generate a model for the road trajectory. However, this approach turned out to be unsatisfactory because small alignment errors accumulated and anomalies perturbed the correlation peak.

To overcome these problems, four refinements were introduced:

(a) Cumulative road cross-section model

(b) Trajectory extrapolation

(c) Anomaly detection

(d) Masked correlation.

Instead of aligning consecutive RCSs, each RCS is aligned with a cumulative RCS model, based on an exponentially weighted history of previously aligned RCSs. Parabolic extrapolation of past correlation peaks is used to predict the future road trajectory. The predicted trajectory is used to guide the tracker past areas where the correlation peak is unsatisfactory. Anomalies are detected by comparing the aligned RCS with the RCS model. Corresponding pixels that significantly disagree are marked as potential anomalies. The cross-correlation is then repeated, masking out the anomalous pixels to obtain a more accurate alignment.

Steps for the refined tracking algorithm are given below:

(1) Based on past road center points and directions, extrapolate the position of the road center K feet ahead.

(2) Extract the road cross section (RCS) intensities along a line perpendicular to the direction of the road at the extrapolated center point.

(3) Use cross-correlation to find displacement of the current RCS with respect to a model (RCS model) that is dynamically constructed by the road tracker.

(4) Generate a mask indicating the positions of anomalous pixels that deviate from the RCS model.

(5) Recorrelate over the unmasked pixels.

(6) Update the RCS model using only the valid points of the current RCS at the best alignment. Update is done using an exponentially decaying average.

(7) Adjust the position of the road center according to the location of the correlation peak.

(8) Detect anomalies as being significant deviations from the RCS model.

(9) Repeat steps 1-8 until the edge of the image is encountered or the RCS model becomes invalid.

EXPERIMENTAL RESULTS

In the experiments shown here, the road tracker was interactively started by indicating the following information for each road segment:

<X0,Y0>	center of road lane
theta0	direction of road at <X0,Y0>
w	nominal width of road

The freeway example in Figure 1 conforms well to the above model, as shown by the overlay results in Figure 1b. The bright lines indicate the road trajectory and the bright blobs indicate potential anomalies.

The simplistic model that a road consists of well-correlated intensity cross-sections clearly breaks down in the example shown in Figure 2a, where the road surface changes from concrete to asphalt on the overpass. Certainly the RCS model generated for the asphalt will not match the intensities in this globally changed road surface.

When the tracker encounters the surface change a high percentage of the pixels in the RCS will be anomalous (Figure 2b). When this occurs, the tracker extrapolates ahead and tries to reacquire the road. If the road is not reacquired within the length of the longest expected anomaly, the tracker then assumes that a pavement transition has occurred and establishes a new RCS model.

Most of the anomalies marked in Figure 2b are due to road surface changes. All four vehicles were found also. A later section will discuss basic changes to the control structure of the current program to eliminate the false alarms occurring from the surface changes.

Figures 3a and 3b show results for a freeway interchange on-ramp loop. This example is interesting since the road curves rather tightly, and the road surface changes at approximately the same place where the road trajectory changes from a circular arc to a straight line.

Figures 4a and 4b show a very complicated example of road forks, changes in lane width, and intersections. For the lanes tracked, all vehicles and at least portions of the road surface marks (arrows and words) were found. In a developed road expert system, the data base should help significantly in handling the complexities of this image by knowing the locations of forks, intersections, lane-width changes, etc. This information will help in interpreting the cause of RCS model changes.

In marked contrast with the situation in most of the previous figures, figure 5a shows a rather poorly defined dirt road with little evidence of wear patterns. Figure 5b shows the successful results of the road tracker. Most of the anomalies marked were due to shadows cast by sparsely foliated trees.

DISCUSSION

The preceding examples demonstrate the capabilities and limitations of the present tracking algorithm. The algorithm has shown surprising ability to contend with a wide variety of road situations, including total change in the road surface. The use of masked cross-correlation techniques eliminates the potential perturbances to the road track by anomalies. Trajectory extrapolation enables the tracker to reacquire the road after detecting that the road surface has changed. All results were obtained using the same program and the same detection and threshold criteria; no attempt was made to "fine-tune" the parameters individually for each example.

One defect of the present algorithm is the attempt to do too much in one pass along the road. In particular, in the present system, anomaly marking begins before road-surface changes have been detected. The false alarms created by this defect can be eliminated either by backtracking when a road transition is found, or by performing the detailed anomaly detection as a second pass along the road, using the road-course and surface-change knowledge produced by the tracker.

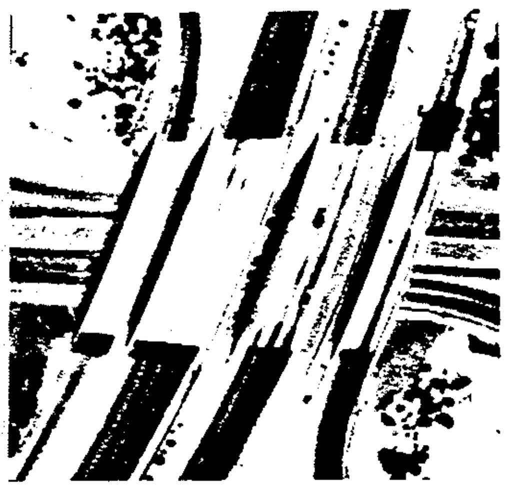
The road tracker presently operates as an independent module. As a component of a larger road-expert system, it will be started from the output of a map-guided road-detection algorithm operating on lower-resolution imagery. Data-base knowledge can also be used in the tracking algorithm to increase reliability and reduce false alarms in anomaly detection. Such knowledge might consist of previous imagery of the same area or geometric knowledge about locations of road forks, intersections, overpasses, surface changes, lane-width changes, etc. To exploit such knowledge, it is necessary to establish geometric correspondence between the image and the data base coordinate system. If, for example, a road anomaly corresponds to a known surface marking on the map or appears in the same place in previous images, then it is probably a surface marking rather than a vehicle. Similarly, the use of an illumination model can help to distinguish objects casting shadows from surface markings.

We plan to acquire and digitize images taken under diverse viewing conditions such as partial cloud coverage, snow cover, oblique viewing angles, and seasonal variations. This will introduce a new set of problems for the tracking algorithm such as non visibility of road segments due to clouds or occluding objects and major photometric differences between images of the same area. The use of a map data base and sources of knowledge will be essential to guide the interpretation of such images.

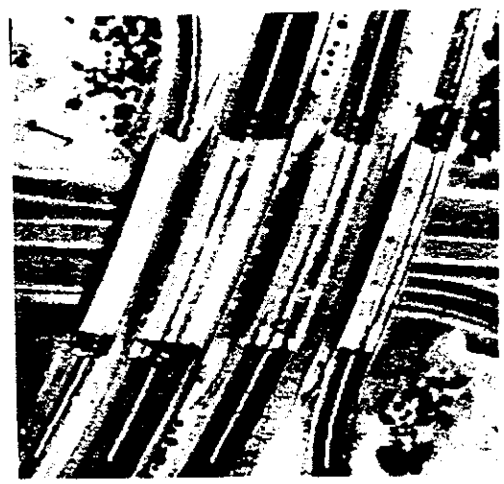
With the planned enhancements and improvements, it should be possible to detect potential vehicles with very high hit rates and low false alarm rates in difficult imagery. This capability is a central component of an overall road-monitoring system.

1a

1b

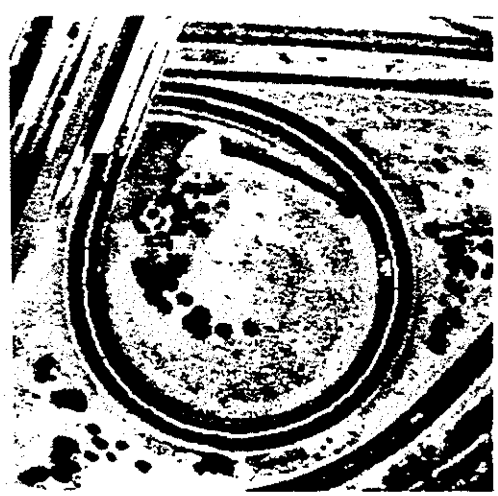


2a



2b

3a



3b